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Legumes on Illinois Soils

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LEGUMES ON ILLINOIS SOILS

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Jerome Edward Readhimer

ENTITLED "Legumes on Illinois Soils"

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Agriculture

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HEAD OF DEPARTMENT OF Agronomy

Legumes on Illinois Soils.

The problems of maintaining the fertility already in the soil, and of increasing the supply where it has become depleted are of the utmost importance to every farmer. Of the three elements of fertility,-nitrogen, phosphorus, and potassium,-which are of commanding importance because of their relative scarcity and expensiveness, the first named should be especially interesting to the farmer. Nitrogen is the most important element of plant food,-if any one element can be considered more important than another,- because of the larger amounts used by plants, because of its relative costliness if obtained in the commercial way, and because it is much more easily lost when applied to the soil.

There are large areas of soils in our own state in which the nitrogen supply has become so depleted as to render it very difficult, any longer, to grow remunerative crops; and in which the supply of organic matter has been so nearly exhausted as to preclude the possibility of preserving the best physical condition of the soil. These considerations have led to an attempt on the part of the writer to investigate some of these problems.

For the purpose of the experiment, soils were collected from several of the large soil-areas of the state in which the above named conditions mainly exist. Soils were taken from

near Vienna, Johnson County, representing the old worn hill soils of the unglaciated part of the state. This soil area is found principally in the seven counties of the state lying south of the range of hills known as the Ozark Spurs. The Vienna soil is typical of the area in which it is found. It is a reddish colored silt loam, badly worn from long continued cultivation and the rolling nature of the surface. In the virgin state, this soil is uniformly productive, being especially adapted to the production of wheat. The field from which the sample was taken is a good representative of the fields of the area. It has been cropped almost continuously for 75 years with practically no fertilizers of any kind being applied. Chemical analysis shows that these soils are markedly acid, very deficient in nitrogen, and more or less deficient in phosphorus.

Samples were taken from near Cutler on the line between Perry and Randolph Counties and from Odin, Marion County, representative of the large soil-area known as the Lower Illinoisan Glacial Prairie type. This area comprises the whole or parts of about thirty counties, lying chiefly between the Wabash and Kaskaskia rivers, north of the Ozark Spurs and south of the Shelbyville Moraine. The Cutler and Odin soils are classed as gray colored silt loams of the prairie type. The soil particles are very fine, and not being held apart by organic matter, have a tendency to run together and form a hard, compact surface. The subsurface, at a depth of about eighteen

inches, consists of a very fine grained clay approaching the character of hard pan. These soils are well adapted to the growing of wheat, and when in the fresh state, give large yields. They have been cropped heavily to wheat, and are badly run down. The soils are very deficient in phosphorus and low in nitrogen. The organic matter is much depleted, and the soils are so acid that it is difficult to grow the legumes, especially the clovers.

Samples were taken from near Virginia, Cass County, in the area designated, the Middle Illinoisan Glaciation. This area comprises chiefly the counties and parts of counties between the Kaskaskia and Illinois rivers and south of the Shelbyville Moraine. It in cludes such counties as Cass, Menard, Morgan, Sangamon, Green, and parts of Christian, Bond, Montgomery, St. Clair, and others.

The principal type is a dark brown loam, well supplied with organic matter and only slightly acid. The phosphorus content, while considerably higher than in the Lower Illinoisan Glaciation, is still much lower than that of the normal fertile soil. The nitrogen supply is fairly abundant as yet. The Virginia soil is a little better than the average. It is a blacker prairie soil, more abundantly supplied with organic matter and the mineral elements.

Lastly, samples were taken from near Antioch, Lake County. This soil represents the higher and more rolling parts of the Wisconsin Moraine area, comprising the counties in the northeastern part of the state.

The Antioch soil is a light gray colored clay soil. It is a close grained soil which runs together and bakes badly. The subsurface and subsoils are heavy clays, very hard and compact, approaching closely the nature of hard-pan. The soil is distinctly acid, low in organic matter and nitrogen, and not very well supplied with phosphorus, though rich in potassium.

The soil from each field was taken to a depth of seven inches, filled into eight stone jars or pots eleven inches deep and ten and one-half inches in diameter, and the pots numbered from one to eight, inclusive.

The plan of the experiment as first outlined was to compare the power of the legumes,- alfalfa, cowpeas, red clover, soybeans, and vetch to fix free atmospheric nitrogen in the different soils; and secondly, to compare the yield and composition of the roots and stubble with the tops, and to determine the value of the roots and stubble to supply organic matter and nitrogen to the soil.

For this purpose, the eight pots were divided into two series of four pots each. One series included the pots numbered one, six, seven, and eight, while the other series included the pots numbered two, three, four, and five. Pots one, six, seven, and eight, were sown to alfalfa after being treated as follows: Pots number one were heated to 120°C. for several hours to destroy any alfalfa bacteria that might be present in the soils; pots number six were inoculated with the alfalfa bacteria; pots number seven were inoculated and given an appli-

cation of six grams of acidulated bone meal per pot; pots number eight were inoculated and given applications of six grams of acidulated bone meal and three grams of sulphate of potash per pot. Pots numbered two, three, four and five were inoculated with the proper bacteria, and then planted as follows: pots number two were sown to soybeans; pots number three, to vetch; pots number four, to cowpeas; and pots number five, to red clover .

The seeds were sown about the first of February, 1903. The plants were kept growing continuously for one year, only being mowed when necessary. Where the plants matured in a shorter time than a year, as the soybeans and cowpeas, they were replanted as soon as harvested. During this time, the alfalfa was cut seven times, viz:- May 23, June 28, July 25, Sept. 3, Oct. 8, Nov. 30, and Jan. 28. The soybeans were planted three times, the last planting, however, not maturing. The vetch was cut twice, July 4, and Nov. 28. The cowpeas grew two crops; while the red clover was cut three times, July 25, Sept. 3, and Nov. 25. The roots of the soybeans and cowpeas were carefully removed from the soil after each cutting, while in the case of the alfalfa, vetch and red clover, the roots were not removed until the end of the experiment, late in January, 1904.

The parts of the plant above ground, and the roots and stubble, after they were washed free of dirt, were dried in the shade to constant weight, the weights of the different parts taken, including the seeds in the case of the soybeans and cowpeas; and finally, the total plant above ground and the roots

and stubble were analyzed separately for nitrogen.

Complete analyses of the soils were made by the Chemistry Department of the Experiment Station, while the nitrogen content of each pot of soil was determined both before and after growing the crops, by the writer. No difference in the nitrogen content of the pots could be detected between the first and last determination, so only the first is made use of in the following discussions.

Analyses of the Soils.

Table No. 1. First 7 inches. In per cents of the whole.

	Antioch.	Cutler.	Odin.	Vienna.	Virginia.
Insoluble Matter	88.462	90.220	89.380	89.8[illegible]7	78.852
Carbon Dioxide					
Organic Carbon					
Nitrogen	.156	.107	.148	.090	.249
Phosphorus	.044	.024	.031	.040	.045
Potassium	.298	.169	.193	.208	.422
Lime Requirements					

If these percentages be reduced to pounds of the elements per acre, we have the following results:

Analyses of the Soils.

Table No. 2. First 7 inches. In pounds per Acre.

	Antioch.	Cutler.	Odin.	Vienna.	Virginia.
Nitrogen	3594	2397	3315	2016	5578
Phosphorus	986	538	694	896	1008
Potassium	6675	3786	4323	4659	9453
Lime requirements					

Analyses of the Soils by Pots.

Table No. 3. In per centages of Nitrogen, first 7 inches.

Location of Soil.	Pot 1.	Pot 2.	Pot 3.	Pot 4.	Pot 5.	Pot 6.	Pot 7.	Pot 8.
Antioch	.165	.166	.166	.166	.166	.166	.163	.166
Cutler	.085	.088	.088	.088	.087	.088	.085	.087
Odin	.120	.132	.127	.121	.126	.127	.126	.126
Vienna	.192	.093	.090	.093	.090	.090	.090	.087
Virginia	.230	.232	.236	.234	.234	.234	.236	.231

By reducing the above percentages to pounds of Nitrogen per acre we have the following results:

Analyses of the Soils by Pots.

Table No. 4. In Pounds of Nitrogen per Acre, first 7 inches.

Location of Soil.	Pot. 1.	Pot. 2.	Pot. 3.	Pot. 4.	Pot. 5.	Pot. 6.	Pot. 7.	Pot. 8.
Antioch	3696	3718	3718	3718	3718	3718	3651	3718
Cutler	1926	1971	1971	1971	1949	1971	1904	1949
Odin	2688	2957	2845	2710	2822	2845	2822	2822
Vienna	2061	2083	2016	2083	2016	2016	2016	1949
Virginia	5152	5197	5286	5241	5241	5241	5286	5174

The best possible care was given the plants during their growth, but, unfortunately, the same person could not attend to them throughout. Because of this, the matter of watering and keeping the plants free from insects, such as the plant lice and the small red spider which infest green-houses, was at times neglected. Some of the pots were kept too wet, which had a more damaging effect on the plants than where not enough water was supplied. The insects named above were very annoying at times. They were especially bad on the vetch and red clover, and succeeded in almost destroying them toward the close of the season.

Notwithstanding all of the drawbacks, the results have a meaning, and for purposes of comparison can be depended on as being fairly reliable.

One very noticeable fact, and which changed the plan of the experiment considerably, made itself evident early in the course of the work. The number one pots were to be used as

check pots to which all the others were to be referred. In order to make sure that nothing should interfere with the accuracy and reliability of the checks, the soils were heated to 120° C. for several hours, to destroy any inoculating bacteria that the soils might contain. The heating had exactly the opposite effect from what was expected of it. The bacteria were no doubt killed, but on the other hand, certain changes, physical or chemical, or both, were produced that had a very remarkable effect on the growth of the plants. If table No. 5 be consulted, it will readily be seen that the yields of alfalfa, both tops and roots, on the number one pots, are greater in almost every case than the corresponding yields from the number six pots where the soils were inoculated with the alfalfa bacteria. In the case of the Antioch soil, there was a yield of 105 gm. against 89 gm. for the tops and 35 gm. against 31 gm. for the roots. The Odin soil gives a yield of 56 gm. against 39gm. for the tops and 15gm. against 17gm. for the roots. The Vienna soil gives a yield of 46gm. against 34gm. for the tops and 23gm. against 17gm. for the roots. The Virginia soil gives a yield of 68gm. against 61gm. for the tops and 26gm. against 27gm. for the roots. In only two instances, in the case of the yield of roots on the Odin and Virginia soils, did the number six pots give larger yields than were obtained from the number one pots. The average increase in yields of the number one pots over the number six pots was 22% for the tops and 8% for the roots.

The nature of the changes produced in the soils by heating is not known, but they(the changes) were probably largely chemical. At any rate, a large amount of plant-food must have been rendered readily available. If we examine table No. 12, it will be seen that the tops and roots combined removed from the Antioch soil, 707 lbs of nitrogen per acre, while from the Odin soil 360 lbs were removed. From the Vienna soil, 330 lbs, and 422 lbs, from the Virginia soil. This nitrogen must have all, or practically all, come from the supply in the soil, because the heating destroyed any nitrogen-gathering bacteria that might have existed in the soil before heating, and none were supplied afterwards. Late in the season the Virginia soil became slightly inoculated, but no tubercles were found on the roots of the plants growing in the other pots.

It is interesting to note that the nitrogen removed from these heated soils amounted to 19 per cent of all the nitrogen found in the 1st 7 inches of the Antioch soil; 12 1/2 per cent of that found in the Odin soil; 16 per cent of that in the Vienna soil, and 8 per cent of that found in the Virginia soil.

The heating of soils can be of but little practical importance, but may be of interest from a scientific standpoint. So far as known to the writer, little has ever been published along this line, and practically nothing is known about the changes produced by heating. Dr. Wiley, Chief of the Bureau of Chemistry of the United States Department of Agriculture, has reported similar observations in his work with pot-culture experiments, but has not given any explanation of the

effects produced.

It is a common observation that plants grow much ranker where a brush or log pile, or a hay or straw stack has been burned than on the surrounding soil. In some parts of the state, the potato fields are covered 6 to 10 inches deep with wheat straw to act as a mulch. When the potatoes are harvested, this straw is usually burned. Invariably the crop is better on this soil the following year than on the surrounding. The accepted explanation has always been that a large quantity of potassium and some phosphorus were added in an easily available form by the ashes. This explanation might hold true if it were not for the fact that when the soil is so deficient in nitrogen that only minimum yields are possible, large applications of easily available phosphorus and potassium only slightly increase the yields. Is it not probable, then, that the increased growth over these burned areas is largely due to the changes which take place in the soil during the heating rather than to the addition of large quantities of mineral elements from the burned material? It will be interesting to follow the investigations farther to determine if possible the nature and extent of the changes which the soil undergoes upon being heated.

Yield of Tops and Roots in Grams per Pot.

Table No. 5. Weights relate to the air-dry state.

Name of Crop.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa, Tops, first cutting.	1	Heated	13.43	...... *	5.81	1.02	12.29
Alfalfa, Tops, last cutting.	"	"	9.17	- - - -	3.47	4.41	6.59
Alfalfa, Tops, all cuttings.	"	"	105.45	- - - -	55.90	45.79	68.25
Alfalfa, Roots.	"	"	34.79	- - - -	14.53	22.58	26.19
Alfalfa, Tops, and Roots.	"	"	140.24	- - - -	70.43	68.37	94.44
Alfalfa, Tops, first cutting.	6	Bac.	17.82	6.00	7.03	4.16	9.64
Alfalfa, Tops, last cutting.	"	"	8.72	4.85	4.09	4.21	9.05
Alfalfa, Tops, all cuttings.	"	"	89.04	30.35	38.61	33.52	63.50
Alfalfa, Roots.	"	"	30.50	16.44	17.06	16.71	27.08
Alfalfa, Tops, and Roots.	"	"	119.54	46.79	55.67	50.23	90.58
Alfalfa, Tops, first cutting.	7	P Bac.	18.76	8.73	12.44	8.95	12.75
Alfalfa, Tops, last cutting.	"	"	10.91	6.04	8.50	7.11	12.03
Alfalfa, Tops, all cuttings.	"	"	111.09	40.72	74.49	59.92	80.54
Alfalfa, Roots.	"	"	39.33	19.36	27.97	25.89	32.79
Alfalfa, Tops, and Roots.	"	"	150.42	60.08	102.46	85.79	113.33
Alfalfa, Tops, first cutting.	8	PKBac.	28.35	7.38	12.52	9.88	11.79
Alfalfa, Tops, last cutting.	"	"	12.91	7.24	8.89	7.10	9.93
Alfalfa, Tops, all cuttings.	"	"	132.67	38.93	69.22	63.37	73.52
Alfalfa, Roots.	"	"	48.05	16.55	38.70	31.62	35.23
Alfalfa, Tops, and Roots.	"	"	180.72	55.48	107.92	94.99	108.75

* this pot was broken early in the experiment, consequently no yields were taken.

Table No. 5.(Con.) Weights relate to the air-dry state.

Name of Crop.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Soybeans, vines.	2	Bac.	66.25	35.37	39.56	33.43	53.62
Soybeans, seeds.	"	"	19.29	12.60	15.43	12.68	16.82
Soybeans, total tops.	"	"	85.84	47.97	54.99	46.11	70.44
Soybeans, roots.	"	"	3.07	5.78	5.78	4.63	8.02
Soybeans, tops, and roots.	"	"	93.61	53.75	60.73	50.74	78.46
Vetch, tops.	3	Bac.	63.55	28.97	31.07	27.89	66.97
Vetch, roots.	"	"	2.90	0.77	0.92	1.62	2.40
Vetch, tops, and roots.	"	"	66.45	28.74	31.99	29.51	69.37
Cowpeas, vines.	4	Bac.	90.85	42.14	47.33	37.21	75.70
Cowpeas, seeds.	"	"	21.52	7.16	3.08	0.76	11.65
Cowpeas, total tops.	"	"	112.37	49.30	50.41	37.97	87.35
Cowpeas, roots.	"	"	18.69	8.90	10.11	7.65	15.42
Cowpeas, tops, and roots.	"	"	131.06	58.20	60.52	45.62	102.77
Red Clover, tops.	5	Bac.	124.18	71.34	79.14	67.66	114.87
Red Clover, roots.	"	"	11.98	9.39	10.20	[illegible].41	15.67
Red Clover, tops, and roots.	"	"	13[illegible].16	80.73	89.34	67.07	130.54

Rank of Legumes as to Nitrogen Content and Total Yield.

Table No. [illegible].

	Legume	Antioch	Cutler	Odin	Vienna	Virginia
Nitrogen Rank.	Red Clover.	2	1	1	1	1
Total Yield Rank.	"	1	1	1	1	1
Nitrogen Rank.	Cowpeas	3	3	4	4	3
Total Yield Rank.	"	2	2	3	4	2
Nitrogen Rank.	Soybeans	4	4	2	3	4
Total Yield Rank.	"	4	3	2	2	4
Nitrogen Rank.	Vetch	5	5	5	5	5
Total Yield Rank.	"	5	5	5	5	5
Nitrogen Rank.	Alfalfa	1	2	3	2	2
Total Yield Rank.	"	3	4	4	3	3

Leaving out of consideration the heated soils, and comparing the yields of alfalfa from the numbers six, seven, and eight pots, it is seen that the yields were largely increased by the application of phosphorus alone, and still further slightly increased, in most instances, by the addition of potassium to the phosphorus. The average increase in the yield of tops on the number seven pots over the number six pots, Table No.5., anounted to 44%, that of the roots, 35%, and of the total, tops and roots, 41%. The average increase in the yield of tops on the number eight pots over the number seven pots amounted to only 3%, that of the roots, 17%, and of the total, tops and roots, 7%. While the phosphorus treatment gave a largely increased yield over the untreated soils, the addition of potassium to the phosphorus further increased the yield very little, especially of tops. In fact, on some of the soils, Cutler and Virginia, there was an actual decrease in total yield of 10% and 4%, respectively. In the case of the Cutler soil, there was a decrease in the yield of both tops and roots, while in the Virginia soil there was a decrease only in the yield of tops. The Odin soil gave a decreased yield in tops, but the increased yield of roots was sufficient to give an increased total yield. The Antioch soil gave the largest yield of both tops and roots, but the largest per cent ofincrease in yields of the number seven pots over the number six pots was on the Odin soils, with an increase of 84%. The other soils follow in order: Vienna, 71%; Cutler, 28%; Antioch, 26%; and Virginia, 25%. The increase

in yield of the number eight pots over the number six pots was as follows: Odin, 94%; Vienna, 89%; Antioch, 51%; Virginia, 20%; and Cutler, 19%.

Leaving out the Antioch soil, the yields of the different soils varied directly as the nitrogen content of the soils, and on the untreated soils, the number six pots, in almost the same proportion. The yield of the Antioch soil was out of all proportion to the others, which fact I am not able to explain.

In the second series, where no fertilizers were applied, but where different legumes were compared, we find the same law generally holding true, viz., that the yield varied directly as the nitrogen content ofthe soil. In this series, however, the Cutler soil with a slightly less nitrogen content than the Vienna soil, gave a slightly larger yield with every legume but the vetch and in that case the two yields were practically the same. The yields on the Antioch soil were again out of proportion.

Comparing the different legumes on the same soil, using the number six pots of the first series for the alfalfa, we have some interesting results. On the Antioch soil, the red clover gave the largest total yield with 136.16 gms per pot. The cowpeas gave the second largest yield with 131.06 gms per pot; the alfalfa was third with 119.54 gms per pot; the soybeans gave fourth with 93.61 gms per pot, while the vetch gave the least yield with 66.45 gms per pot. On the Cutler soil the red clover stands first with 80.73 gms per pot; the cowpeas second with 58.20 gms per pot; the soybeans third, with 53.75 gms per pot; the alfalfa fourth with 46.79 gms per pot, and the vetch last with 28.74 gms per pot. On the Odin soil, the red

clover stands first with a yield of 89.34 grams per pot; the soy-beans, second with 60.73 grams per pot; the cowpeas third with 60.52 grams per pot; the alfalfa fourth with 55.67 grams per pot, and the vetch last with 31.99 grams per pot. Red clover stands first on the Vienna soil with 76.07 grams per pot; the soybeans second with 50.74 grams per pot; the alfalfa third with 50.23 grams per pot; the cowpeas fourth with 45.62 grams per pot and the vetch last with 29.51 grams per pot. The Virginia soil gives red clover a yield of 130.54 grams; cowpeas second with 102.77 grams; alfalfa third with 90.58 grams; soybeans fourth with 78.46 grams, and vetch last with 69.37 grams per pot.

Taking the average yield per pot, the red clover stands first with 102.57 grams, the cowpeas second with 79.65 grams, the alfalfa third with 72.56 grams, the soybeans fourth with 67.46 grams, and the vetch last with 45.21 grams per pot.

If the yields of the tops and roots be compared separately, the order in which the total yields stand will be somewhat changed. Taking the average yields of tops, the red clover stands first with 91.44 grams, the cowpeas second with 67.48 grams, the soybeans third with 61.01 grams, the alfalfa fourth with 51.00 grams, and the vetch last with 43.49 grams per pot. For the roots the alfalfa stands first with 21.56 grams, the cowpeas second with 12.15 grams, the red clover third with 11.13 grams, the soybeans fourth with 6.45 grams, and the vetch last with 1.72 grams per pot. While the red clover stands first both as to total yield and the yield of tops, it is only third in the yield of roots. The cowpeas stand second in the yield

of tops, roots, and total yield. The soybeans stand third in the yield of tops, fourth in the yield of roots, and fourth in the total yield. Alfalfa stands only fourth in the yield of tops, but first in the yield of roots, and third in the total yield. The vetch stands last in the yield of tops, roots, and total. In no case did the vetch yield as well as any of the other legumes.

The yield of tops and roots in tons per acre is given in Table no. 7. The largest yield of tops of any legume on any soil not fertilized was for red clover on the Antioch soil with a yield of 9.93 tons per acre. The largest yield of roots was for alfalfa on the Antioch soil with a yield of 2.44 tons per acre. The largest total yield was for red clover on the Antioch soil with 10.89 tons per acre. The cowpeas gave a total yield of 10.48 tons per acre on the same soil, while red clover yielded a total of 10.44 tons per acre on the Virginia soil. The smallest yield of tops was for vetch on the Vienna soil with 2.23 tons per acre. The smallest yield of roots was for vetch on the Cutler soil with only .06 of a ton per acre. The smallest total yield was also for vetch on the Cutler soil with 2.30 tons per acre.

Yield of Tops and Roots in Tons per Acre.

Table No. 7. Weights relate to the air-dry state.

Name of Crop.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa, Tops.	1	Heated	8.44		4.47	3.66	5.46
Alfalfa, Roots.	"	"	2.78		1.16	1.81	5.46
Alfalfa, Total.	"	"	10.22		5.63	5.47	7.55
Alfalfa, Tops.	6	Bac.	7.12	2.43	3.09	2.68	5.08
Alfalfa, Roots.	"	"	2.44	1.31	1.36	1.34	2.17
Alfalfa, Total.	"	"	9.56	3.74	4.45	4.02	7.25
Alfalfa, Tops.	7	P Bac.	8.89	3.26	5.96	4.79	6.44
Alfalfa, Roots.	"	"	3.15	1.5[illegible]	2.24	2.07	2.62
Alfalfa, Total.	"	"	12.04	4.81	8.20	6.86	9.06
Alfalfa, Tops.	8	PK Bac	10.61	3.11	5.54	5.07	5.88
Alfalfa, Roots.	"	"	3.8[illegible]	1.32	3.09	2.53	2.82
Alfalfa, Total.	"	"	14.45	4.43	8.63	7.60	8.70
Soybeans, Tops.	2	Bac.	[illegible].84	3.84	4.40	3.69	5.64
Soybeans, Roots.	"	"	0.6[illegible]	0.46	0.46	0.37	0.64
Soybeans, Total.	"	"	7.49	4.30	4.86	4.06	6.28
Vetch, Tops.	3	Bac.	5.08	2.24	2.49	2.23	5.36
Vetch, Roots.	"	"	0.23	0.06	0.07	0.13	0.19
Vetch, Total.	"	"	5.31	2.30	2.56	2.36	5.55

Yield of Tops and Roots in Tons per Acre.

Table No. 7.(Con.) Weights relate to the air-dry state.

Name of Crop.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Cowpeas, Tops.	4	Bac.	8.99	3.94	4.03	3.04	6.99
Cowpeas, Roots.	"	"	1.49	0.71	0.81	0.61	1.23
Cowpeas, Total.	"	"	10.48	4.65	4.84	3.65	8.22
Red Clover, Tops.	5	Bac.	9.93	5.71	6.33	5.41	9.19
Red Clover, Roots.	"	"	0.96	0.75	0.82	0.67	1.25
Red Clover, Total.	"	"	10.89	6.46	7.15	6.08	10.44

Relative Yield of Tops and Roots.

Table No. [illegible]. Expressed in percentages of the whole.

Name of Crop.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia.	Avor. of Roots.
Alfalfa, tops.	1	Heated	75		80	67	72.5	
Alfalfa, roots.	"	"	25		20	[illegible]	27.[illegible]	2[illegible].4
Alfalfa, tops.	6	Bac.	7[illegible]	[illegible]4.5	69	[illegible]7	70	
Alfalfa, roots.	"	"	2[illegible]	[illegible]	31	[illegible]	30	31.1
Alfalfa, tops.	[illegible]	P Bac.	[illegible]4	[illegible]	75	[illegible]9.5	[illegible]1	
Alfalfa, roots.	"	"	2[illegible]	[illegible]	27	[illegible].5	2[illegible]	2[illegible].9
Alfalfa, tops.	[illegible]	P K Bac.	7[illegible]	71	6[illegible]	[illegible]	[illegible]7.5	
Alfalfa, roots.	"	"	2[illegible].5	29	3[illegible]	[illegible]	32.[illegible]	[illegible]1.4
Soybeans, tops.	2	Bac.	9[illegible]	[illegible]	9[illegible]	90	90	
Soybeans, roots.	"	"	[illegible]	11	1[illegible]	10	10	10.[illegible]
Vetch, tops.	[illegible]	Bac.	9[illegible]	9[illegible].5	97	93	97	
Vetch roots.	"	"	4	[illegible]	3	7	[illegible]	4.1
Cowpeas, tops.	[illegible]	Bac.	[illegible]	[illegible]	[illegible]2.5	[illegible]2.5	[illegible]5	
Cowpeas, roots.	"	"	14	1[illegible]	17.5	1[illegible].5	1[illegible]	1[illegible]
Red Clover, tops.	[illegible]	Bac.	91	8[illegible]	[illegible]	[illegible]	[illegible]	
Red Clover, roots.	"	"	[illegible]	12	11	1[illegible]	1[illegible]	11.[illegible]

Table No. 8. showes the relative yield of tops and roots expressed in percentages of the whole. The average percentages of the roots from the untreated soils stand in the following order: Alfalfa 31.1; cowpeas 15.8; red clover 11.0; soybeans 10.0; and vetch 4.1. The largest per cent of roots in any case was for alfalfa on the Cutler soil with 35 1/2 %, and the smallest per cent was for vetch on the Odin and Virginia soils with only 3%. The average per cents for all the legumes on different soils arranged in order stand as follows: Vienna 15.7%; Cutler 15.4%; Odin 14.5%; Virginia 14.0%, and Antioch 12.4%. The general average was 14.4%. The poorer soils gave the larger percentage of roots in each case. The average for the three soils Cutler, Odin, and Vienna was 15.2%, while the average for Antioch and Virginia was only 13.2%.

In the case of the alfalfa pots, the relative yield of roots to tops was smallest on the heated soils. Neither did the application of mineral fertilizers increase the proportion of roots to any extent. The average percent of roots for the heated soils was 26.4, while for the untreated soils it was 31.1. For the phosphorus treatment the percent was 28.9, and for the phosphorus and potassium treatment it was 31.4. The soils poorest in nitrogen, here again, gave the largest per cent of roots to tops, the average for the Cutler, Odin, and Vienna soils being for the heated soils 26 1/2% against 26 1/4 for the average of the Antioch and Virginia soils. The same soils on the untreated pots gave as an average 33.2% against 28% for

Percent of Nitrogen in Tops and Roots.

Table No.9.   Expressed in terms of air-dry matter.

Name of Crop.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia	Aver. %.
Alfalfa, tops.	1	Treated	3.35		3.43	3.54	3.12	3.36
Alfalfa, roots.	"	"	2.56		2.20	1.93	1.94	2.16
Alfalfa, tops.	6	Bac.	3.43	3.54	3.27	3.51	3.50	3.45
Alfalfa, roots.	"	"	2.29	2.42	2.31	2.39	2.62	2.41
Alfalfa, tops.	7	P Bac.	3.39	3.30	3.50	3.58	3.35	3.42
Alfalfa, roots.	"	"	2.70	2.41	2.37	2.37	2.62	2.49
Alfalfa, tops.	8	P K Bac.	3.38	3.33	3.31	3.57	3.46	3.41
Alfalfa, roots.	"	"	2.71	2.67	2.52	2.48	2.72	2.62
Soybeans, tops.	2	Bac.	2.61	2.61	2.97	3.01	2.43	2.73
Soybeans, roots.	"	"	1.17	1.32	1.42	1.53	1.12	1.31
Vetch, tops.	3	Bac.	2.99	2.49	2.42	2.42	2.55	2.57
Vetch, roots.	"	"	2.63	2.27	2.68	2.29	2.74	2.52
Cowpeas, tops.	4	Bac.	2.15	2.42	2.12	2.34	2.17	2.24
Cowpeas, roots.	"	"	1.21	1.74	1.18	1.47	1.44	1.41
Red Clover, tops.	5	Bac.	2.43	2.47	2.30	2.45	2.56	2.44
Red Clover, roots.	"	"	2.46	2.11	2.23	2.22	2.60	2.32

the others; for the phosphorus treatment they gave 29.8% against 27.5, and for the phosphorus and potassium treatment they gave 32.7% against 29.5% for the other soils. The highest yield of roots to tops on the alfalfa series was for the phosphorus and potassium treatment on the Odin soil with 36%, and the lowest was for the heated Odin soil with only 20%.

Table No.9. shows the percentages of nitrogen in the tops and roots of the legumes grown on the different types of soil and under different treatments. On the alfalfa series, the percents of nitrogen for both the tops and roots on the different soils, and on the same soil, but under different treatments, vary but little. The nitrogen content of the plants grown on the poorer soils was just about as high as it was in the case of the more fertile soils. The application of mineral fertilizers did not increase the per cent of nitrogen in the tops any, and only slightly in the roots. The average per cent of nitrogen for the heated soils was 3.36 for the tops and 2.16 for the roots. For the untreated soils, it was 3.45 for the tops and 2.41 for the roots. For the phosphorus treated soils, the tops contained 3.42% of nitrogen and the roots 2.49%. For the phosphorus and potassium treated soils, the per cent of nitrogen in the tops was 3.41 and in the roots it was 2.62. The average per cent of nitrogen for all treatments of the same soil was for Antioch, tops 3.39, roots 2.56. For the Cutler soil, tops 3.39, roots 2.50. For the Odin soil, tops 3.38, roots 2.35. For Vienna soil, tops 3.55, roots 2.29. For the Virtinia soil, tops 3.36, roots 2.48.

The variation in the nitrogen content of the soybeans, on the different soils was somewhat greater than in the case of the alfalfa. For the tops the variation was from 2.[illegible]% on the Virginia soil to 3.01% on the Vienna soil. The average for all the soils was 2.7[illegible]%. For the roots, the nitrogen varied from 1.12% on the Virginia soil to 1.55% on the Vienna soil, with an average of 1.31%. The variation in the nitrogen content of the vetch was also greater than in the case of the alfalfa. The nitrogen in the tops varied from 2.42% on the Odin and Vienna soils to 2.99% on the Antioch soil, with an average of 2.57%. The nitrogen in the roots varied from 2.27% on the Cutler soil to 2.74% on the Virginia soil with an average of 2.52%. The nitrogen in the tops of the cowpeas varied but little-from 2.12% on the Odin soil to 2.42% on the Cutler soil, the average being 2.[illegible]4%. The nitrogen content of the roots varied from 1.13% on the Odin soil to 1.74% on the Cutler soil, the average being 1.41%. For the red clover tops the nitrogen content was very constant, varying only from 2.30% on the Odin soil to 2.[illegible]% on the Virginia soil, with an average of 2.44%. The nitrogen in the roots was not quite so constant, varying from 2.11% on the Cutler soil to 2.[illegible]0% on the Virginia soil, the average being 2.32%.

The legumes stand in the following order as to the per cent of nitrogen in their tops-alfalfa, 3.45; soybeans, 2.7[illegible]; vetch, 2.57; red clover, 2.44; cowpeas, 2.[illegible]4. For the roots, the order is vetch, 2.52; alfalfa, 2.41; red clover, 2.32; cowpeas, 1.41;

soybeans, 1.3[illegible]. The nitrogen content of the tops was usually considerably higher than that of the roots. In the case of the alfalfa, the content of nitrogen in the roots was 70% of that in the tops. For the soybeans it was 4[illegible]%; for the vetch, 9[illegible]%; for the cowpeas, 63%, and for the red clover the nitrogen content of the roots was 95% of that in the tops. In the cases of the vetch and red clover, the per cent of nitrogen in the roots was actually higher in several instances than it was in the tops, namely, on the Odin and Virginia soils in the case of the vetch, and on the Antioch and Virginia soils in case of the red clover. While the per cent of nitrogen in the roots is usually quite high, often almost as high as it is in the tops, yet the actual amount of nitrogen in the roots as compared to that in the tops is very much smaller.

Table No. 10 shows the amount of nitrogen found in the tops and roots of each of the legumes grown on each of the soils expressed in grams of nitrogen per pot. By examining this table it is seen that for the untreated soils, the red clover gives the largest amount of nitrogen for the tops in every case but one, and that in the case of the Antioch soil where the alfalfa gave the largest amount. For the roots, the alfalfa yields very much greater amounts. Comparing the amounts by soils, the Antioch soil leads in the case of every legume. The other soils stand in about the order of their nitrogen content, namely, Virginia, Odin, Vienna, Cutler.

If we compare the amounts of nitrogen in the tops and roots of the various legumes by soils, we have the tops standing

Nitrogin in Tops and Roots, Expressed in Grams per Pot.

Table No.10.

Name of Crop.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa, tops.	1	Heated	3.53		1.92	1.63	2.13
Alfalfa, roots.	"	"	0.89		0.32	0.44	0.51
Alfalfa, total.	"	"	4.42		2.24	2.07	2.64
Alfalfa, tops.	6	Bac.	3.06	1.07	1.26	1.18	2.22
Alfalfa, roots.	"	"	0.70	0.40	0.39	0.40	0.71
Alfalfa, total.	"	"	3.76	1.47	1.65	1.58	2.93
Alfalfa, tops.	7	P Bac.	3.77	1.34	2.61	2.15	2.70
Alfafla, roots.	"	"	1.06	0.47	0.66	0.61	0.86
Alfalfa, total.	"	"	4.83	1.81	3.27	2.76	3.56
Alfalfa, tops.	8	P K Bac	4.48	1.30	2.30	2.26	2.54
Alfalfa, roots.	"	"	1.30	0.44	0.98	0.78	0.96
Alfalfa, total.	"	"	5.78	1.74	3.28	3.04	3.50
Soybeans, tops.	2	Bac.	2.23	1.25	1.63	1.39	1.71
Soybeans, roots.	"	"	0.09	0.08	0.08	0.07	0.09
Soybeans, total.	"	"	2.32	1.33	1.71	1.46	1.80
Vetch, tops.	3	Bac.	1.80	0.70	0.75	0.67	1.71
Vetch, roots.	"	"	0.08	0.02	0.025	0.04	0.07
Vetch, total.	"	"	1.88	0.72	0.775	0.71	1.78

Table No.10.(Con.)

Name of Crop.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Cowpeas, tops.	4	Bac.	2.42	1.19	1.07	0.89	1.89
Cowpeas, roots.	"	"	0.23	0.15	0.12	0.11	0.22
Cowpeas, total.	"	"	2.65	1.34	1.19	1.00	2.11
Red Clover, tops.	5	Bac.	3.02	1.76	1.82	1.66	2.84
Red Clover, roots.	"	"	0.29	0.20	0.23	0.19	0.41
Red Clover, total.	"	"	3.31	1.96	2.05	1.85	3.25

Rank of Soils as to Nitrogen Content and Total Yield.

Table No.11.

	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Nitrogen rank.	6	Bac.	1	5	3	4	2
Total Yield rank.	"	"	1	5	3	4	2
Nitrogen rank.	7	P Bac.	1	5	3	4	2
Total Yield rank.	"	"	1	5	3	4	2
Nitrogen rank.	8	P K Bac	1	5	3	4	2
Total Yield rank.	"	"	1	5	3	4	2
Nitrogen rank.	2	Bac.	1	5	3	4	2
Total Yield rank.	"	"	1	4	3	5	2
Nitrogen rank.	3	Bac.	1	4	3	5	2
Total Yield rank.	"	"	2	5	3	4	1

Rank of Soils as to Nitrogen Content and Total Yield.

Table No.11.(Con.)

	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Nitrogen rank.	4	Bac.	1	3	4	5	2
Total Yield rank.	"	"	1	4	3	5	2
Nitrogen rank.	5	Bac.	1	4	3	5	2
Total Yield rank.	"	"	1	4	3	5	2

in this order,-Antioch soil- alfalfa, red clover, cowpeas, soybeans, vetch; Cutler soil-red clover, soybeans, cowpeas,alfalfa, vetch; Odin soil- red clover, soybeans, alfalfa,cowpeas, vetch; Vienna soil- red clover, soybeans, alfalfa, cowpeas, vetch; Virginia soil-red clover, alfalfa, cowpeas, soybeans and vetch tied. The roots stand in the same order for all the soils, viz., alfalfa, red clover, cowpeas, soybeans,and vetch.

The treatments given the soils in the case of the alfalfa series, greatly increased the amount of nitrogen removed by the tops and roots, not by increasing the per cent of nitrogen in the tops and roots, but by increasing the yield of them. The average amount of nitrogen removed by the tops of the alfalfa on the heated soils was 16% greater than it was in the case of the untreated soils. For the roots, however, it was 2% less. Where phosphorus was applied the tops removed 30%, and the roots, 29% more nitrogen than was removed by the tops and roots from the untreated soils. Where both phosphorus and potassium were applied the tops and roots removed from the soils an average of 32% and 42% more nitrogen respectively than was removed by the tops and roots from the untreated soils. The potassium alone, increased the amount of nitrogen removed by the tops only 2%, while it increased the amount removed by the roots 13%.

Table No.12. shows the amount of nitrogen in pounds per acre contained in the tops and roots of the different legumes. From this table it is seen that large amounts of nitrogen are secured by these plants. In the case of the alfalfa on the untreated

Nitrogen in Tops and Roots, Expressed in Pounds per Acre.

Table No.12.

Kind of Legume.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa, tops.	1	Heated	564.8		307.7	260.2	340.6
Alfalfa, roots.	"	"	142.6		51.2	69.8	81.3
Alfalfa, total.	"	"	707.4		358.9	330.0	421.9
Alfalfa, tops.	6	Bac.	490.1	171.8	202.1	188.3	355.7
Alfalfa, roots.	"	"	111.7	63.5	63.0	63.8	113.4
Alfalfa, total.	"	"	601.8	235.3	265.1	252.1	469.1
Alfalfa, tops.	7	P Bac.	602.6	215.0	417.1	342.2	431.7
Alfalfa, roots.	"	"	169.9	74.7	106.1	98.1	137.4
Alfalfa, total.	"	"	772.5	289.7	523.2	440.3	569.1
Alfalfa, tops.	8	P K Bac	717.4	207.4	367.7	361.9	407.0
Alfalfa, roots.	"	"	208.3	71.0	156.0	125.4	153.3
Alfalfa, total.	"	"	925.7	278.4	523.7	487.3	560.3
Soybeans, tops.	2	Bac.	357.1	200.3	261.3	221.9	273.8
Soybeans, roots.	"	"	15.0	12.2	13.0	11.2	14.2
Soybeans, total.	"	"	372.1	212.5	274.3	233.1	288.0
Vetch, tops.	3	Bac.	288.0	111.4	120.2	107.8	273.1
Vetch, roots.	"	"	12.2	2.7	3.8	5.9	10.4
Vetch, total.	"	"	300.2	114.1	124.0	113.7	283.5

Nitrogen in Tops and Roots, Expressed in Pounds per Acre.

Table No.12.(Cont.)

Kind of Legume.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Cowpeas, tops.	4	Bac.	386.6	190.9	170.9	142.1	303.2
Cowpeas, roots.	"	"	36.2	24.8	19.0	17.9	35.5
Cowpeas, total.	"	"	422.8	215.7	189.9	160.0	338.7
Red Clover, tops.	5	Bac.	482.7	281.9	291.2	265.1	454.4
Red Clover, roots.	"	"	47.0	31.7	36.3	29.8	65.1
Red Clover, total.	"	"	529.7	313.6	327.5	294.9	519.5

soils there were 600 lb. per acre removed from the Antioch soil and 265 lb. per acre removed from the Odin soil. Where phosphorus was applied, the alfalfa took up 772 lb. of nitrogen per acre on the Antioch soil and 523 lb. on the Odin soil. Here we have an increase of 172 lb. and 258 lb. of nitrogen per acre, respectively, due to the application of phosphorus. Where potassium was applied with the phosphorus, the amount of nitrogen taken up on the Antioch soil reached the enormous quantity of 925 lb. per acre. There was no increase in the amount taken up on the Odin soil. The alfalfa took up proportionately large amounts on the other soils.

The amount of nitrogen taken up by the other legumes was considerably less than that taken up by the alfalfa, yet, in many instances, it was very large. The soybeans took up on the Antioch soil 372 lb. and from the Odin soil 274 lb. of nitrogen per acre. The vetch on these same soils, 300 lb. and 124 lb. per acre respectively; while the cowpeas took up 423 lb. and 190 lb. per acre respectively, and the red clover 530 lb. and 327 lb. per acre respectively.

It is interesting to note the amount of nitrogen contained in the roots of the legumes. The roots of the alfalfa contained far more nitrogen than the roots of any of the other legumes. On the untreated soils, the alfalfa roots contained 111 lb. per acre from the Antioch soil and63 lb. from the Odin soil. The soybean roots removed from these same soils 15 and 13 lb. per acre respectively; the vetch roots removed only 12

and 4 lb. per acre respectively; the cowpea roots removed 36 and 19 lb. per acre respectively, and the red clover roots removed 47 and 36 lb. of nitrogen per acre respectively from the Antioch and Odin soils. In the case of every soil, the legumes stand in the following order as regards the amount of nitrogen removed from the soil by their roots:- alfalfa, red clover, cowpeas, soybeans, and vetch.

Table No. 13. shows the relative amounts of nitrogen in the tops and roots expressed in percentages of the whole. In the case of the Antioch soil, 19% of the total amount of nitrogen removed from the soil by the alfalfa, was in the roots, while in the case of the Odin soil, 24% was in the roots. The average amount of nitrogen removed in the roots for all the soils was 23.8% of the whole amount removed. In the case of the soybeans on the Antioch soil, only 4% of the total nitrogen was in the roots, and on the Odin soil, only 5%, the average for all the soils being 5%. The amount removed by the roots of the vetch from the Antioch and Odin soils was 4 and 3% respectively of the total amount, the average for all the soils being 3.7%. The cowpea roots removed from the Antioch and Odin soils 9 and 10% respectively of the total nitrogen removed, with an average of all the soils of 10.4%. The roots of the red clover contained 9 and 11% respectively of the total nitrogen removed from the Antioch and Odin soils, the average for all the soils being 10.5%. The roots of the alfalfa on the Cutler

Relative Amount of Nitrogen in Tops and Roots.

Table No. 13. Expressed in percentages of the whole.

Kind of Legume.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia.	Aver. of Roots.
Alfalfa, tops.	1	Heated.	80		86	79	81	
Alfalfa, roots.	"	"	20		14	21	19	18.5
Alfalfa, tops.	6	Bac.	81	73	76	75	76	
Alfalfa, roots.	"	"	19	27	24	25	24	23.8
Alfalfa, tops.	7	P Bac.	78	74	80	78	76	
Alfalfa, roots.	"	"	22	26	20	22	24	22.8
Alfalfa, tops.	8	P K Bac	77.5	74.5	70	74	73	
Alfalfa, roots.	"	"	22.5	25.5	30	26	27	26.2
Soybeans, tops.	2	Bac.	96	94	95	95	95	
Soybeans, roots.	"	"	4	6	5	5	5	5.0
Vetch, tops.	3	Bac.	96	97.5	97	95	96	
Vetch, roots.	"	"	4	2.5	3	5	4	3.7
Cowpeas, tops.	4	Bac.	91	88.5	90	89	89.5	
Cowpeas, roots.	"	"	9	11.5	10	11	10.5	10.4
Red Clover, tops.	5	Bac.	91	90	89	90	87.5	
Red Clover, roots.	"	"	9	10	11	10	12.5	10.5

Relative Value of the Legumes for the Nitrogen in the Tops and Roots

Table No.14. Referred to red clover as a standard with a val. of 100

Legume	Parts of Plants.	Antioch	Cutler	Odin	Vienna	Virginia
Red Clover	Tops.	100	100	100	100	100
"	Roots.	100	100	100	100	100
"	Total.	100	100	100	100	100
Cowpeas	Tops.	80	68	59	54	67
"	Roots.	79	75	52	58	54
"	Total.	80	68	58	54	65
Soybeans	Tops.	74	71	90	84	60
"	Roots.	31	40	35	37	22
"	Total	70	68	83	79	55
Vetch	Tops.	60	40	41	40	60
"	Roots.	28	10	11	21	17
"	Total.	57	37	38	38	55
Alfalfa	Tops.	101	61	69	71	78
"	Roots.	242	200	170	211	173
"	Total.	114	75	80	85	90

soil contained 27% of all the nitrogen removed from that soil, while the roots of the vetch on the same soil contained only 2.5% of the total nitrogen removed.

The application of mineral fertilizers had very little effect on the relative amounts of nitrogen in tops and roots. Where phosphorus alone was applied, the roots contained on an average for all soils 22.8% of the total nitrogen against 23.8% for the untreated soils. Where both phosphorus and potassium were applied, the roots contained 26.2% of the nitrogen against 23.8% for the untreated soils.

It has already been seen that the roots of the legumes under discussion contain considerable amounts of nitrogen. When these roots decay in the ground the nitrogen gradually becomes available and may be used by the plants which follow. In this way the roots become of importance as green manure. Since this nitrogen is partly, at least, obtained from the atmosphere, it may be considered as an actual addition to the supply already in the soil, and, as such, has a money value. If we measure its value in terms of the number of bushels of corn that it will produce or in terms of tons of manure that it is equivalent to, we can more easily form an idea of its importance. Taking only the untreated soils for comparison, we see from Table No.15. that the alfalfa roots from the Antioch and Virginia soils contain as much nitrogen per acre as is found in 11 tons of ordinary barnyard manure, while the roots from each of the Cutler, Odin, and Vienna soils contain as much nitrogen per acre as is found in 6 tons of manure. The soybean roots are

Value of the Roots as Nitrogenous Fertilizers,

Expressed in Tons of Manure per acre.

Table No.15. The nitrogen content of manure taken as 10 lb. per ton.

Kind of Legume.	Pot No.	Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa, lb. nitrogen	1	Heated	142.6		51.2	69.8	81.3
Manure, equiv. in tons			14.26		5.12	6.98	8.13
Alfalfa, lb. nitrogen	6	Bac.	111.7	63.5	63.0	63.8	113.4
Manure, equiv. in tons			11.17	6.35	6.30	6.38	11.34
Alfalfa, lb. nitrogen	7	P Bac.	169.9	74.7	106.1	98.1	137.4
Manure, equiv. in tons			16.99	7.47	10.61	9.81	13.74
Alfalfa, lb. nitrogen	8	PK Bac.	208.3	71.0	156.0	125.4	153.3
Manure, equiv. in tons			20.83	7.10	15.60	12.54	15.33
Soybean, lb. nitrogen	2	Bac.	15.0	12.2	13.0	11.2	14.2
Manure, equiv. in tons			1.50	1.22	1.30	1.12	1.42
Vetch, lb. nitrogen	3	"	12.2	2.7	3.8	5.9	10.4
Manure, equiv. in tons			1.22	0.27	0.38	0.59	1.04
Cowpeas, lb. nitrogen	4	"	36.2	24.8	19.0	17.9	35.5
Manure, equiv. in tons			3.62	2.48	1.90	1.79	3.55
Red Clover, lb. nitrogen	5	"	47.0	31.7	36.3	29.8	65.1
Manure, equiv. in tons.			4.70	3.17	3.63	2.98	6.51

much less valuable than the roots of the alfalfa, still they contain considerable quantities of nitrogen. The soybean roots on the Antioch and Virginia soils contain nitrogen per acre equivalint to 1.5 tons of manure, while on the Cutler, Odin, and Vienna soils respectively, they contain nitrogen equivalent to 1.25 tons of manure. The vetch roots are of still less importance. On the Antioch and Virginia soils they contain only as much nitrogen per acre as is contained in about 1 ton of manure, and for the other soils they are equivalent to only about .5 ton of manure. The roots per acre of the cowpeas on the Antioch and Virginia soils are equivalent to about 3.5 tons of manure, and for the other soils they are equivalent to about 2 tons of manure. The roots of the red clover on the Antioch and Virginia soils are equivalent to 4.75 and 6.5 tons of manure respectively, while for the other soils they are equivalent to about 3 tons of manure for each soil. If we measure the value of the roots in terms of bushels of corn, the alfalfa roots on the Antioch and Virginia soils contain sufficient nitrogen per acre to produce more than 100 bushels, while the roots per acre on the Cutler, Odin, and Vienna soils contain sufficient nitrogen to produce about 65 bushels. The nitrogen per acre in the roots of the Soybeans will produce only about 15 bushels of corn on the Antioch and Virginia soils, and about 12 bushels on each of the other three soils. The nitrogen per acre in the vetch roots is less still, and is equivalent to that contained in about 15 bushels of corn for the

Antioch and Virginia soils, and to less than that in 5 bushels for the other soils. For the Antioch and Virginia soils, the cowpea roots contain enough nitrogen per acre to produce 35 bushels of corn. On the Cutler, Odin, and Vienna soils there is sufficient nitrogen per acre to produce about 20 bushels. The roots of the red clover on the Antioch soil contain enough nitrogen per acre to produce about 50 bushels of corn. On the Virginia soil there was enough nitrogen to produce 6 bushels, and for each of the other soils there was enough for about 30 bushels.

Besides supplying nitrogen to the soil, the roots of the legumes have another very important function, the adding of organic matter or humus to the soil, a function which is probably as important as the supplying of nitrogen. There is still another important function which the roots of legume perform, especially on certain soils, which will be discussed later.

Table No. 16., shows the value of the roots of the legumes as organic matter expressed in tons of manure. It is seen here that the roots of alfalfa per acre on the Antioch and Virginia soils will furnish as much organic matter to the soils as will 9 tons of average barnyard manure. The roots from the Cutler, Odin, and Vienna soils will furnish as much per acre as 5.5 tons of manure. The roots of the soybeans on the Antioch and Virginia soils are equivalent to about 2.5 tons of manure, and on the other soils to about 1.75 tons. The value of the roots of vetch for furnishing organic matter to the soil was very

Value of Roots as Organic Matter,

Expressed in Tons of Manure.

Table No.16. Dry-matter of manure taken at 25% of the whole.

Kind of Legume.	Pot No.	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Alfalfa Roots, Tons.	1	Heated	2.78		1.16	1.81	2.10
Manure, Tons.	"	"	11.13		4.65	7.22	8.38
Alfalfa Roots, Tons.	6	Bac.	2.44	1.32	1.37	1.34	2.17
Manure, Tons.	"	"	9.76	5.26	5.46	5.35	8.66
Alfalfa, Roots, Tons.	7	P Bac.	3.15	1.55	2.24	2.07	2.62
Manure, Tons.	"	"	12.58	6.20	8.95	8.28	10.49
Alfalfa Roots, Tons.	8	PKBac.	3.84	1.32	3.10	2.53	2.82
Manure, Tons.	"	"	15.38	5.30	12.38	10.12	11.27
Soybeans Roots, Tons.	2	Bac.	0.65	0.46	0.46	0.37	0.64
Manure, Tons.	"	"	2.58	1.85	1.84	1.48	2.56
Vetch Roots, Tons.	3	Bac.	0.23	0.06	0.07	0.13	0.19
Manure, Tons.	"	"	0.93	0.25	0.30	0.52	0.77
Cowpea Roots, Tons.	4	Bac.	1.50	0.71	0.81	0.61	1.23
Manure, Tons.	"	"	5.98	2.85	3.24	2.45	4.94
Red Clover Roots, Tons.	5	Bac.	0.96	0.75	0.82	0.67	1.25
Manure, Tons.	"	"	3.83	3.00	3.26	2.69	5.02

much less than for any of the other legumes. For the Antioch and Virginia soils they are equivalent to less than a ton of manure, and for the other soils, less than a half-ton. The cowpea roots for the Antioch soil are equivalent to 6 tons of manure; on the Virginia soil they are equivalent to 5 tons; on the Cutler and Odin soils to about 3 tons, and on the Vienna soil to about 2.5 tons. The red clover roots are equal in value to about 5 tons for the Virginia soil, and to about 4 tons for the Antioch soil, andto about 3 tons for the Cutler, Odin, and Vienna soils respectively.

Where the soils were treated with the mineral fertilizers, the value of the roots was greatly increased. Where the nitrogen in the roots of the alfalfa was sufficient to produce 63 bushels of corn on the untreated Odin soil, it was sufficient to produce 106 bushels on the same soil treated with phosphorus, and 156 bushels on the soil treated with phosphorus and potassium. The other soils give similar results.

The roots of the legumes in decaying perform a two-fold function- they affect the soil chemically and physically. Chemically speaking the roots add nitrogen directly to the soil, and affect the phosphorus and potassium content indirectly. The nitrogen is obtained directly from the atmosphere through the simbiotic action of the root-bacteria. When the roots decay this nitrogengoes to increase the supply already existing in the soil. The roots do not make any real addition of phosphorus or potassium to the soil, but change the form of that already

present. Most of the phosphorus and potassium in the soil exists in a form but slightly soluble. Often therefroe, the plant is unable to obtain them in sufficient quantities for the most perfect development. In the decaying roots they are in a more easily available form for the use of the growing plants.

Legumes being deep rooters perform another important function in bringing phosphorus and potassium up from the lower layers of the soil to the surface where they will be more available to the shallow rooting crops which follow. This is an especially important function on soils in which large stores of these mineral elements are present in the lower layers, but comparatively scarce in the surface layers. This is true of many soils in this state, especially as to the potassium content of the lower Illinois Glaciation.

Beside the beneficial effects derived from the roots of legumes mentioned above, they have an indirect chemical value. In the decay of vegetable matter, acids are formed as one of the products. These acids in their reactions with the soil compounds attack and decompose the insoluble particles of minerals and rocks of which the soil is composed. Carbon dioxide is also given off as one of the products of decay. This is absorbed by the soil water and greatly increases its power of dissolving the rocks and minerals.

The value of a green manure from a physical standpoint is no less important than from a chemical. The deeply penetrating roots of the legumes upon decaying leave channels in the hard

subsoil which allow the air and water to circulate more freely, thus warming up the soil and making it more habitable for the nitrifying and other bacteria which live in the soil. The texture of the soil is also improved by the addition of humus, and its power to absorb and retain moisture is increased. It makes a clay soil porous and crumbly when dry and less stiff when wet. It prevents evaporation and puddling, allows a freer circulation of air, makes it more pervious to water, thus accelerating the drainage in wet weather and favoring the upward capillary movement of the water in dry seasons. In sandy soils the humus also acts beneficially, but in the opposite direction. It makes the sand more retentive of water, more coherent, and lessens the tendency to leaching.

Humus, then, becomes of very great importance to the farmer in the successful growing of crops. Plant food may be supplied in the greatest abundance, but unless humus is supplied along with it the soil cannot be expected to give the best results.

In discussing the relative value of the various legumes as green manure crops, it must be borne in mind that alfalfa is not employed usually in the general rotation or as a catch crop. The tops are rich in nitrogen, and are heavy yielders, and would furnish large amounts of valuable manure if plowed under. The roots are also valuable, not only because of the large amount of nitrogen and organic matter which they add tothe soil, but also because of the deep rooting habit which they

have. The soil must be left in a far better physical condition after having a good growth of alfalfa roots plowed up. This , however, cannot happen very often.

As to the other legumes,the red clover gave the largest yield of tops and largest total yield on every soil, and the largest yield of roots in every case but one, namely, the cowpeas on the Antioch soil. The cowpeas gave a larger yield of tops and a larger total yield than the soybeans on every soil except the Odin and Vienna types, and a larger yield of roots on every soil. The soybeans gave a larger yield of tops, of roots, and of total than the vetch on every soil. The vetch yielded poorest on every soil. It, however, gave a fair yield of tops, but the yield of roots was insignificant.

There can be no doubt that red clover, where it succeeds well, as it does on the Antioch and Virginia soils, is a more satisfactory legume to use in the rotation than cowpeas or soybeans. It can be sown with the oats or wheat, then used either as a permanent part of the rotation or as a catch crop. If allowed to stand over the following year, a crop of hay and a crop of seed can be cut, and the after growth, together with the roots, can be plowed under late in the fall or the next spring as green manure for the corn crop. If used as a catch crop, it has nearly a years growth to plow under as green manure. It is very doubtful if clover can be used to good advantage as a catch crop sown after the oats or wheat are harvested, or in the corn when it is laid by. There is not time for it to

make very much growth. For a catch crop of this kind, cowpeas and soybeans, or even vetch should doubtless prove superior.

On soils like the Cutler, Odin, and Vienna types where clover fails to do well, at least while they are in their present condition, the cowpea or soybean would undoubtedly prove more satisfactory, either as crops of the general rotation, or as catch crops. There is no doubt that either of these can be used to good advantage when sown after the wheat is cut off or in the corn. It is rather late to sow them after the oats are harvested. They are killed by the first heavy frost so must be sown as early as possible to derive the greatest good from them. They can be left on the ground over winter or plowed under late in the fall. Vetch might be made use of as a catch-crop on any of the soils. It could be sown with or after the oats, after the wheat, and in the corn when it is laid by, and left until the following spring. Not being easily affected by the cold, it grows late into the winter and starts up early in the spring. Used thus it should make a large amount of material to plow under for the corn crop. For the Cutler, Odin, Vienna, and similar soils there is probably no legume better suited for either the general rotation or as a catch-crop than the cowpea or soybean. Each has its good points to commend it and each has its advocates. For the production of seed the soybean is undoubtedly superior to the cowpea. On the Cutler, Odin, and Vienna soils, the soybeans yielded seed at the rate of 33.5, 41, and 33.75 bu. per acre respectively against a yield of 19, 3.25 and 2 bu. per acre respectively for the cowpeas. For vines, either to make

hay out of or to plow under as green manure the two are practically of equal value. The soybeans yielded 3.8, 4.4, and 3.7 tons per acre respectively against a yield of 3.9, 4, and 3 tons per acre for the cowpeas. In the yield of roots, the cowpeas were superior in the case of every soil, yielding 0.71, 0.81, and 0.61 tons per acre respectively against a yield of 0.46, 0.46, and 0.37 tons per acre for the soybeans. The average per cent of roots to tops on the three soils was 10 for the soybeans and 16.66 for the cowpeas.

There is very little to choose between the cowpeas and the soybeans so far as the feeding or fertilizing value of the hay is concerned. The average per cent of nitrogen in the soybean hay including the seed was 2.88 against 2.29 for the cowpeas. The roots of the cowpeas, on the other hand, not only yielded a much greater amount of organic matter, but it was slightly richer in nitrogen than the roots of the soybeans.

Where it is practicable to grow it, there is no legume that con take the place of or even approach red clover as a green manure crop. It fits into the rotation better, produces a larger amount of tops and roots, adds more nitrogen to the soil at a smaller expenditure of money, than any other legume. It can safely be said that where clover will grow successfully, farming is easy.

After the legumes were cut off and the roots removed the soils were given the following treatments:

The number one or heated soils were given no treatment. To the

number two, number three, number four, and number five soils were applied 20gms of air-slaked lime and 12 gms of steamed bone meal per pot. To the number six soils were applied 20gms of air-slaked lime per pot. To the number seven soils were applied 20gms of air-slaked lime and 9gms of steamed bone meal per pot, 6gms of acidulated bone meal per pot having been applied in the spring of 1903. To the number eight soils were applied 20gms of air-slaked lime, 9gms of steamed bone meal, and 3gms of potassium sulphate per pot, 6gms of acidulated bone meal and 3gms of potass sulphate having been applied in the spring of 1903. No nitrogen of any kind was applied to any of the soils.

The wheat(Minnesota Spring) was sown the 9th of February, 1904. After a time it was thinned to exactly 15 stalks per pot. The pots were all treated exactly alike at all times, giving them the best care possible. The wheat grew rapidly from the first, and continued in a thrifty condition throughout its growth. The plants on the number eight soils grew off faster and looked more thrifty for a considerable time than any of the others, but finally the other fertilized wheat over-took them and from then on looked fully as well as they. The wheat on the number six or unfertilized soils was always considerably smaller than that on the other soils. The wheat on the number one or heated soils made good growth from the first. It looked equally as well as that on most of the pots and considerably better than that on the number six soils.

There was no greater difference in the wheat on the different soils than would be expected from the difference in the composition of the soils.

No striking results were obtained from the yields of the wheat. Table 17, pages 51 and 52, shows the yield of grain and straw in grams per pot; table 18, page 53, gives the yield of grain and straw in bushels and tons per acre; table 19, page 54, shows the yield of grain and straw in grams per pot as influenced by the treatment; while table 20, page 55, shows the average yield of grain per head of wheat, and the amount of straw required to produce a unit weight of grain.

Examining table 19, page 54, for the yield after Alfalfa, on the Antioch soil, the phosphorus appeared to benefit the crop slightly, while the potassium seemed to be detrimental. The heated soil of the Cutler series gave the highest yield, there being practically no difference between the other treatments. The large yield from the heated soil in this case is probably due to the fact that no yield was taken from this soil the previous year. On the Odin soil, the phosphorus treatment increased the yield about one third, while the potassium scarcely held its own. On the Vienna soil, phosphorus increased the yield to a considerable extent, while the potassium proved detrimental. On the Virginia soil, about the same results were obtained except that the potassium gave a slight increase.

Where the same mineral fertilizers were used, but different legumes, nothing at all definite can be detected. In the case of the Antioch soil, the wheat following soybeans gave the largest yield, with red clover a close second. On the Cutler soil, the vetch proved the most effective with cowpeas second; on the Odin soil the soybeans were first with the vetch second; on the Vienna soil the vetch was first with the soybeans second, while on the Virginia soil the cowpeas gave the best results with the vetch second. The fact that the wheat yielded so well after the soybeans and the vetch may

be due to the low yields of these crops the year before.

Taking all the data into consideration there is nothing to warrant the drawing of any conclusion excepting that phosphorus produced a considerable increase in the yield.

Yield of Wheat, Grain and Straw, in Grams per Pot.

Table 17 Weights relate to the air-dry state.

		Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Original No. of Stalks	1st.	Soil Heated	15	15	15	15	15
No. of Stalks Harvested	"	Alfalfa.	33	34	23	30	20
Weight of Grain	"	"	19.9	17.0	14.2	13.2	16.6
Weight of Straw	"	"	49.6	55.1	33.8	26.8	39.9
Total Weight	"	"	69.5	72.1	48.0	40.0	56.5
Original No. of Stalks	2nd.	L	15	15	15	15	15
No. of Stalks Harvested	"	Alfalfa.	28	25	17	31	15
Weight of Grain	"	"	21.1	15.5	15.7	11.3	9.6
Weight of Straw	"	"	45.2	31.2	30.1	28.3	20.7
Total Weight	"	"	66.3	46.7	45.8	39.6	30.3
Original No. of Stalks	3rd.	LP	15	15	15	15	15
No. of Stalks Harvested	"	Alfalfa.	31	26	27	30	18
Weight of Grain	"	"	23.6	15.2	22.6	13.1	16.8
Weight of Straw	"	"	56.5	33.8	45.1	38.8	39.6
Total Weight	"	"	80.1	49.0	67.7	51.9	56.4
Original No. of Stalks	4th.	LPK	15	15	15	15	15
No. of Stalks Harvested	"	Alfalfa.	27	22	32	27	21
Weight of Grain	"	"	17.7	15.6	21.6	10.1	17.4
Weight of Straw	"	"	46.1	37.7	51.8	30.1	43.9
Total Weight	"	"	63.8	53.3	73.4	40.2	61.3

Yield of Wheat, Grain and Straw, in Grams per Pot. (Con.)

Weights relate to the air-dry state.

		Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Original No. of Stalks	5th.	LP	15	15	15	15	15
No. of Stalks Harvested	"	Red Clover	39	25	34	19	23
Weight of Grain	"	"	26.5	15.9	20.9	10.7	18.6
Weight of Straw	"	"	62.1	32.7	46.4	24.2	40.4
Total Weight	"	"	88.6	48.6	67.3	34.9	59.0
Original No. of Stalks	6th.	LP	15	15	15	15	15
No. of Stalks Harvested	"	Cow-peas	33	26	29	20	32
Weight of Grain	"	"	21.1	17.6	18.8	11.1	25.7
Weight of Straw	"	"	48.3	40.9	33.5	26.4	59.3
Total Weight	"	"	69.4	58.5	52.3	37.5	85.0
Original No. of Stalks	7th.	LP	15	15	15	15	15
No. of Stalks Harvested	"	Soy-beans	40	25	33	24	27
Weight of Grain	"	"	27.3	17.3	24.0	15.5	19.0
Weight of Straw	"	"	64.9	39.7	53.5	35.4	47.4
Total Weight	"	"	92.2	57.0	77.5	50.9	66.4
Original No. of Stalks	8th.	LP	15	15	15	15	15
No. of Stalks Harvested	"	Vetch	39	28	32	25	29
Weight of Grain	"	"	22.4	20.4	22.8	15.7	22.6
Weight of Straw	"	"	58.8	43.3	50.6	40.3	49.6
Total Weight	"	"	81.2	63.7	73.4	56.0	72.2

Yield of Wheat in Bushels of Grain and Tons of Straw per Acre.

Table 18

		Treatment.	Antioch	Cutler	Odin	Vienna	Virginia
Grain	1st.	Heated Alfalfa	53.0	45.4	37.9	35.3	44.2
Straw			3.96	4.41	2.71	2.14	3.20
Grain	2nd.	L Alfalfa	56.2	41.4	42.0	30.2	25.4
Straw			3.62	2.49	2.41	2.26	1.66
Grain	3rd.	LP Alfalfa	63.0	40.4	60.2	35.0	44.7
Straw			4.52	2.71	3.61	3.10	3.17
Grain	4th.	LPK Alfalfa	47.3	41.7	57.7	27.0	46.5
Straw			3.69	3.02	4.14	2.41	3.81
Grain	5th.	L P Red Clover	70.7	42.3	55.7	28.5	49.5
Straw			4.97	2.62	3.71	1.93	3.23
Grain	6th.	L P Cowpeas	56.3	46.9	50.0	29.7	68.5
Straw			3.86	3.27	2.68	2.11	4.74
Grain	7th.	L P Soybeans	72.8	46.2	64.1	41.3	50.6
Straw			5.19	3.17	4.28	2.84	3.79
Grain	8th.	Vetch	59.7	54.4	60.8	42.0	60.4
Straw			4.70	3.47	4.05	3.22	3.97

Yield of Grain and Straw as Influenced by the Treatment.

Table 19

Grams per pot	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Grain	Heated Alfal-fa	19.9	17.0	14.2	13.2	15.6
Straw		49.6	55.1	33.8	26.8	39.9
Grain	L Alfalfa	21.1	15.5	15.7	11.3	9.6
Straw		45.2	31.2	30.1	28.3	20.7
Grain	L P Alfalfa	23.6	15.2	22.6	13.1	16.8
Straw		56.5	33.8	45.1	38.8	39.6
Grain	L P K Alfalfa	17.7	15.6	21.7	10.1	17.4
Straw		46.1	37.7	51.8	30.1	43.9
Grain	L P Red Clover	26.5	15.9	20.9	10.7	18.6
Straw		62.1	32.8	46.4	24.2	40.4
Grain	L P Cowpeas	21.1	17.6	18.8	11.1	25.7
Straw		48.3	40.9	33.5	26.4	59.3
Grain	L P Soybeans	27.3	17.3	24.0	15.5	19.0
Straw		64.9	39.7	53.5	35.5	47.4
Grain	L P Vetch	22.4	20.4	22.8	15.7	22.6
Straw		58.8	43.3	50.6	40.3	49.6

Average Yield of Grain per Stalk, and Amount of Straw per Unit Weight of Grain.

Table 20

Weight in Grams	Treat-ment.	Antioch	Cutler	Odin	Vienna	Virginia
Grain per stalk	Heated	.60	.50	.62	.44	.83
Straw to grain	Alfalfa	2.49	3.24	2.38	2.02	2.41
Grain per stalk	L	.75	.62	.93	.37	.64
Straw to grain	Alfalfa	2.14	2.01	1.91	2.49	2.15
Grain per stalk	L P	.76	.58	.84	.44	.93
Straw to grain	Alfalfa	2.39	2.23	2.00	2.95	2.36
Grain per stalk	L P K	.66	.71	.68	.37	.83
Straw to grain	Alfalfa	2.60	2.41	2.39	2.98	2.51
Grain per stalk	L P	.68	.63	.61	.56	.81
Straw to grain	Red Clover	2.34	2.06	2.22	2.26	2.12
Grain per stalk	L P	.64	.68	.65	.56	.80
Straw to grain	Cowpeas	2.28	2.32	1.84	2.37	2.31
Grain per stalk	L P	.68	.69	.73	.64	.70
Straw to grain	Soybeans	2.38	2.29	2.23	2.29	2.50
Grain per stalk	L P	.57	.73	.71	.63	.78
Straw to grain	Vetch	2.63	2.12	2.22	2.56	2.19